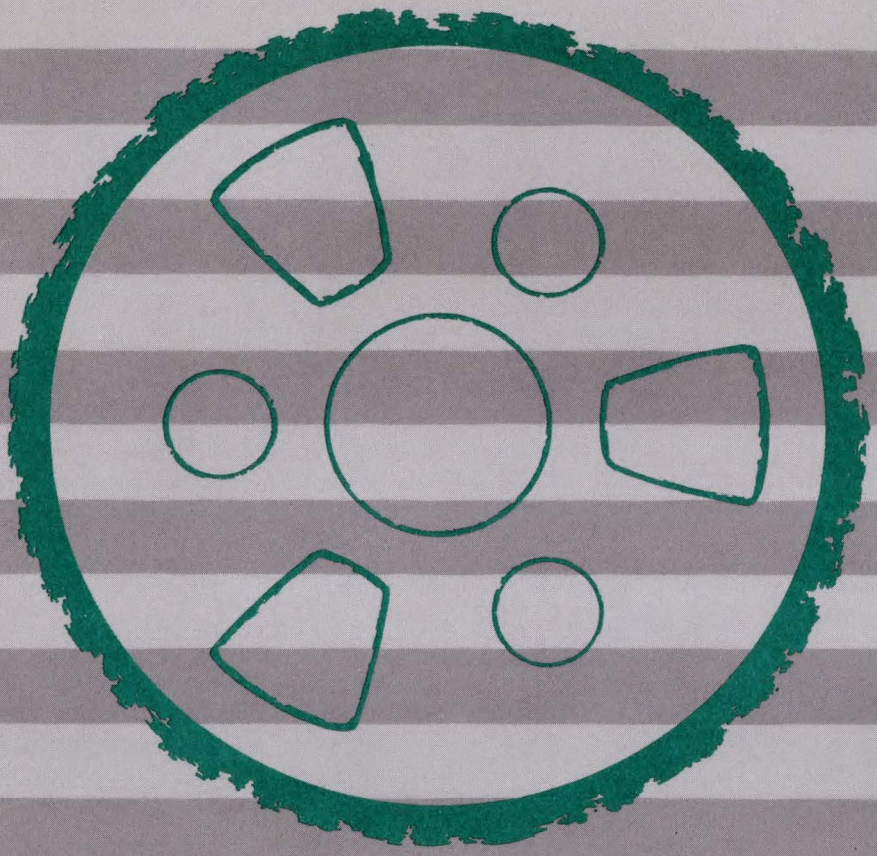

TAPE MEASURE NUMBER 1

How Environment Affects Magnetic Recording Tape

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HOW ENVIRONMENT AFFECTS MAGNETIC RECORDING TAPE

Summary

The increasing emphasis on higher and higher operating and/or storage temperatures for data acquisition apparatus requires a critical appraisal of the behavior of available magnetic recording tapes as their rated operating limits are approached or exceeded.

Among the criteria that bear examination are the dimensional stability, strength and toughness of the substrate, and the chemical stability of the binder and the magnetic material.

Unexpected physical effects can be experienced within the generally accepted "safe" environmental limits. Critical temperatures and observed effects are described.

INTRODUCTION

The influence of temperature and humidity on magnetic recording tape can be related to three general component areas:

The substrate, or base film that serves as the physical carrier for the magnetic coating, which is composed of

a binder, or magnetically inert matrix, and

the active ferromagnetic material.

Temperature limits for safe operation generally are specified in the range of −40° to +80°C. But permanent damage can be experienced within that "safe" range. For example, sustained exposure to uncontrolled environment, particularly temperatures above 25°C, can destroy cellulose-acetate-base tape by embrittlement. Binder degradation begins in the range of +55°C. Permanent shrinkage of polyester-base tapes commences at about 60°C. And temperature-sensitive chemical degradation of the polyester causes accelerated reduction of tensile strength that becomes of serious concern above 100°C. The magnetic material, however, will withstand higher temperatures than either the base film or the binder. It remains chemically stable to about 400°C, above which it reverts to non-magnetic form.

BASE FILMS

Two principal base-film materials are used currently in the United States for magnetic tape: cellulose acetate and Mylar (DuPont's polyester film). Fundamentally, both are transparent films that look very much alike. But their composition and physical properties are vastly different.

Cellulose Acetate. Basic cellulose acetate is a transparent, brittle material. By the addition of suitable softening agents, called plasticizers, it can be made pliable. Cellulose acetate film is made by casting dissolved and plasticized cellulose acetate on the surface of a highly polished drum. Its finished properties depend, to a great extent, on the softening agents added and the success in compounding a homogeneous mixture.

Mylar. Mylar, by way of contrast, is not a mixture. It is a single compound . . . a polymer synthesized from petroleum derivatives. Its inherent flexibility makes the use of plasticizers unnecessary. Chemically, it is polyethylene terephthalate, formed by the condensation reaction between ethylene glycol and terephthalatic acid. Mylar film exhibits outstanding tensile strength, tear resistance and flex life. Many of its superior physical properties are attributed to the mechanical process used in Mylar-film production, in which an oriented molecular pattern is produced rather than the random molecular structure that is characteristic of most organic films.

Molecular Orientation

The mechanical process by which oriented Mylar film is produced from bulk polyester resin is, understandably, a closely guarded trade secret. Moreover, it is not necessary to know exactly "how" in order to fully appreciate the end result. Molecular-orientation techniques are relatively well known to the plastics art; typically, polyethylene films are oriented by extrusion.[1]

There are two basic kinds of polyethylene film. The shape of the extruding-die sections and the

means for post-extrusion film cooling determine the procedures necessary to produce either "blown" or "flat" polyethylene film.

Blown Film. In blown-film extrusion, the molten resin is forced around a mandrel inside a ring-shaped die opening, from which it is extruded in the form of a rather thick tube. The tube is expanded by internal air pressure into a "bubble"—usually about three times the diameter of the die opening—which is retrieved and flattened by a pair of pinch rolls.

A number of factors affect film gauge and quality: die-ring adjustment, resin temperatures, haul-off speeds, die temperatures, blow-up ratios and bubble-cooling rate. In particular, by suitable control of conditions, molecular orientation can be achieved in both machine and transverse directions, resulting in a film having relatively uniform strength in both directions.

Flat Film. In flat-film extrusion, the melt is extruded through a slot into a quench-water bath.

Although flat film has certain advantages over blown film—notably, good gauge control—molecular orientation is predominantly in the machine direction.

Cellulose Acetate or Mylar?

Mylar is superior to cellulose acetate for use as magnetic-recording-tape base film for many reasons; its only relative disadvantage is higher cost. The initial mechanical qualities of Mylar, like tensile strength and tear resistance, are decidedly superior to dimensionally equivalent cellulose acetate. And two properties of acetate make it particularly vulnerable to permanent damage in uncontrolled ambient environments:

It is very hygroscopic, having a humidity coefficient fourteen times as great as Mylar, and

The plasticizer is a volatile component, subject to escape under high-temperature conditions.

Cellulose Acetate Film

The "resistance to heat" of DuPont CA-43 cellulose acetate film is specified[2] as 65° to 105°C. In addition, the manufacturer indicates "substantial changes in physical properties" as the ambient temperature is varied between −20° and +80°C and the relative humidity is changed from 0 to 100%.

Dimensional Stability. Cellulose acetate exhibits positive thermal and humidity coefficients. Its humidity coefficient is greater than that of most magnetic-tape coatings, creating the effect known as "cupping" – differential expansion – on exposure to moisture.

Contrary to expectations, considering the positive thermal coefficient, it has been observed[3] that acetate-base tapes tend to contract rather than expand when heated. Although surprising at first, the effect can be explained by the decrease in humidity as the temperature is raised: shrinkage caused by dehydration exceeds thermal expansion.

Toughness. Loss of plasticizer causes the film to become extremely brittle, impairing its resistance to suddenly applied loads within the ranges encountered in normal tape-recording practice. Thus acetate-base tapes, exposed to abnormally high temperatures in service or storage, may become unalterably sensitive to tensile shock . . . to the extent that reproduction of irreplacable records is impossible in extreme cases.

Mylar Film

The physical and mechanical properties[4] of Mylar film are relatively unaffected throughout the temperature range of −20°C to +80°C. It remains flexible without signs of embrittlement at temperatures as low as −60°C. As the temperature is increased above the second-order transition temperature of 80°C it behaves like an elastomer, finally melting at about 250°C.

Regular Mylar film is bilaterally oriented; that is, the molecules are structurally aligned in both the machine and the transverse directions. In effect, the film can be considered to be pre-stressed—like work-hardened metal. Paradoxically, it is believed that the very mechanism that imparts outstanding physical properties to Mylar film perhaps creates an inherent susceptibility to permanent shrinkage on exposure to moderately high temperatures. Although the effect is small, it is large enough to preclude the use of Mylar film in certain applications requiring exceptional dimensional stability.

Permanent Deformation. If Mylar is exposed to temperatures in excess of 60°C it will shrink irreversibly[5] at a rapidly decreasing time rate.[6] Practically all of the permanent shrinkage will take place in the first ten minutes of exposure.[4] The manufacturer reports that the shrinkage at 150°C in air amounts to less than 5%.

It has been shown that no further shrinkage will result from repeated temperature cycling if the previous limit is not exceeded. This property suggests that a carefully controlled pre-coating shrinkage process might be successfully employed.

The amount of shrinkage to be expected from a random sample of Mylar film is unpredictable because of the unknown thermal history of the sample. Although insufficient data are available for accurate statistical determination of the amount of shrinkage

taking place at specific temperatures, the following quantitative properties have been observed:

SHRINKAGE, PERCENT	TEMP., °C	STRESS, PSI	EXPOSURE PERIOD	OBSERVER (REF.)
Begins	60	125	——	5
0.1-0.8	70	50	10 hrs.	6
0.75	80	125	1-4 hrs.	5
0.50	100	100	17 hrs.	7
1.05	100	125	1-4 hrs.	5
1.25	120	125	1-4 hrs.	5
1.5-2.0	150	——	0.5 hrs.	4

It is obvious that the shrinkage depends in part on the applied stress, or restraining force, as well as environment. An example cited[7] indicates that if the stress is increased from 100 to 500 psi for 17 hours at 100°C the specimen will elongate 0.42% rather than shrink 0.5%. In addition, it is shown that after 170 days of continuous 300-psi stress (presumably at 25°C) an elongation of 0.3% will be reached. After 8 days recovery, residual elongation will be 0.1%. If the stress is increased to 500 psi, these values will be increased to 0.9% and 0.5%, respectively.

Heat Aging. An investigation of the effects of humidity and temperature on useful service life, reported[8] by McMahon, et al, of the Bell Telephone Laboratories, Inc., showed that tensile strength is the property of Mylar most sensitive to degradation.

It was found that as the result of continued hydrolytic degradation by exposure to heat in the presence of moisture—normal atmosphere included— the tensile strength drops sharply when it reaches about two thirds of the initial value. That point was chosen arbitrarily as the limit of safe service life.

Their published data for 0.5-mil Mylar film indicate a safe service life of 0.2 year (73 days) at 90°C and 50% relative humidity. Extrapolation of their data yields an expected life of only about four days at 125°C (250°F). A DuPont Technical Report,[4] on the other hand, shows that a temperature of 150°C is required to reduce the tensile strength by one third in that period of time.

BINDERS

The active ferromagnetic materials commonly used in magnetic recording tapes are in the form of very finely divided particles, usually smaller than one micron in their largest dimension. In bulk form, they are totally useless as magnetic-recording media; to be useful, they must be held together on the substrate by a suitable binding matrix.

Good binders combine flexibility with toughness and produce a coating having high cohesive and adhesive strength. Obtaining a proper balance of these and other desirable properties is a complex problem; it is no wonder that coating formulations and coating-preparation techniques are closely guarded trade secrets. But irrespective of specific differences, most commercial binders are based on some type of thermoplastic resin. Thermosets have been used, but not to any great extent.

Temperature Effects

The performance of many domestic magnetic-tape coatings suggest that binder degradation commences in the range of +55°C.

Embrittlement. Most of the raw thermoplastic resins used are brittle materials that require the addition of a plasticizer to make them pliable enough for magnetic-tape components. If the plasticizer has an inherently low boiling point (high vapor pressure), as many do, the flexibility of the binder is vulnerable to permanent destruction by heat. Frequently, both adhesive and cohesive properties of the coating disappear with the plasticizer and the tape becomes worthless.

Blocking. Migration of the plasticizer is accelerated by heat. "Blocking," which often accompanies plasticizer migration, is observed frequently in the performance of a standard test[9] for "layer-to-layer adhesion."

The procedure involves winding tape tightly on a mandrel and exposing it to an environment of +55°C and 85% relative humidity for 16 to 18 hours, followed by a period of 4 hours at +55°C with "dry heat." Adhesion, or blocking is readily apparent if the tape fails to unwind without assistance.

Softening. The basic thermoplastic resins commonly employed are subject to heat distortion in the range of 55°C to 75°C, although their properties probably are modified by the other components of the heterogeneous mixture comprising the finished binder. Most domestic tape manufacturers specify a safe temperature limit in the order of +70°C.

ACTIVE FERROMAGNETIC MATERIAL

At the present time, the active ferromagnetic material universally used in the United States is gamma-ferric oxide, Fe_2O_3, in the form of acicular particles approximately 0.1 micron in diameter and 0.8 micron long. It is prepared by a reduction/oxidation process from paint-pigment grades of yellow alpha-ferric oxide.

Although information on the high-temperature stability of gamma-ferric oxide is scarce in the literature, it is variously reported[10] to be relatively unstable, going irreversibly into the non-magnetic alpha-ferric oxide form as the temperature exceeds 400°C.

A LOOK TOWARD THE FUTURE

It is likely that the use of organic materials will have to be abandoned in order to take a major step toward truly high-temperature magnetic-recording media. But significant improvements can be made in existing products to extend their usefulness. A program might consist of the following areas of investigation:

Use binder materials having low-vapor pressure plasticizers, or, preferably, requiring none at all.

Develop the process required to pre-shrink Mylar film before it is coated.

Develop organic films using new resins, capable of withstanding higher temperatures.

Apply the active ferromagnetic material by direct-deposition techniques like plating and evaporation.

Develop inorganic substrates and means for direct deposition of active ferromagnetic materials that remain chemically stable at high temperatures.

It is notable that at least two manufacturers currently are marketing magnetic tapes that allegedly fulfill the requirements of the first progressive step—reduction of plasticizer mobility.

The preliminary shrinking process reportedly is used successfully in preparation of Mylar for use as a high-quality, stable drafting film.

Several new resins that appear to be potentially useful have appeared recently. For example, polyurethane, an isocyanate derivative, can be produced in forms not unlike conventional rubber and plastic products. It is claimed[11] to be useful from lower than $-45°C$ to above $+120°C$; some manufacturers report the useful range to be as low as $-60°C$ and as high as $+200°C$.

Technical literature reveals that many firms currently are involved in research and development activities directed toward magnetic-film deposition techniques. However, the emphasis appears to be related to small specimens having high information-storage densities, rather than on continuous processes adaptable to production of magnetic tape having conventional form.

CONCLUSION

Positive steps must be taken to extend its safe operating environmental limits if magnetic-recording tape is to keep pace with other technical apparatus. Although a major break-through in technology and/or materials is required before existing limits can be exceeded to any great degree, the usefulnss of today's products probably can be extended significantly within the framework of the basic limitations.

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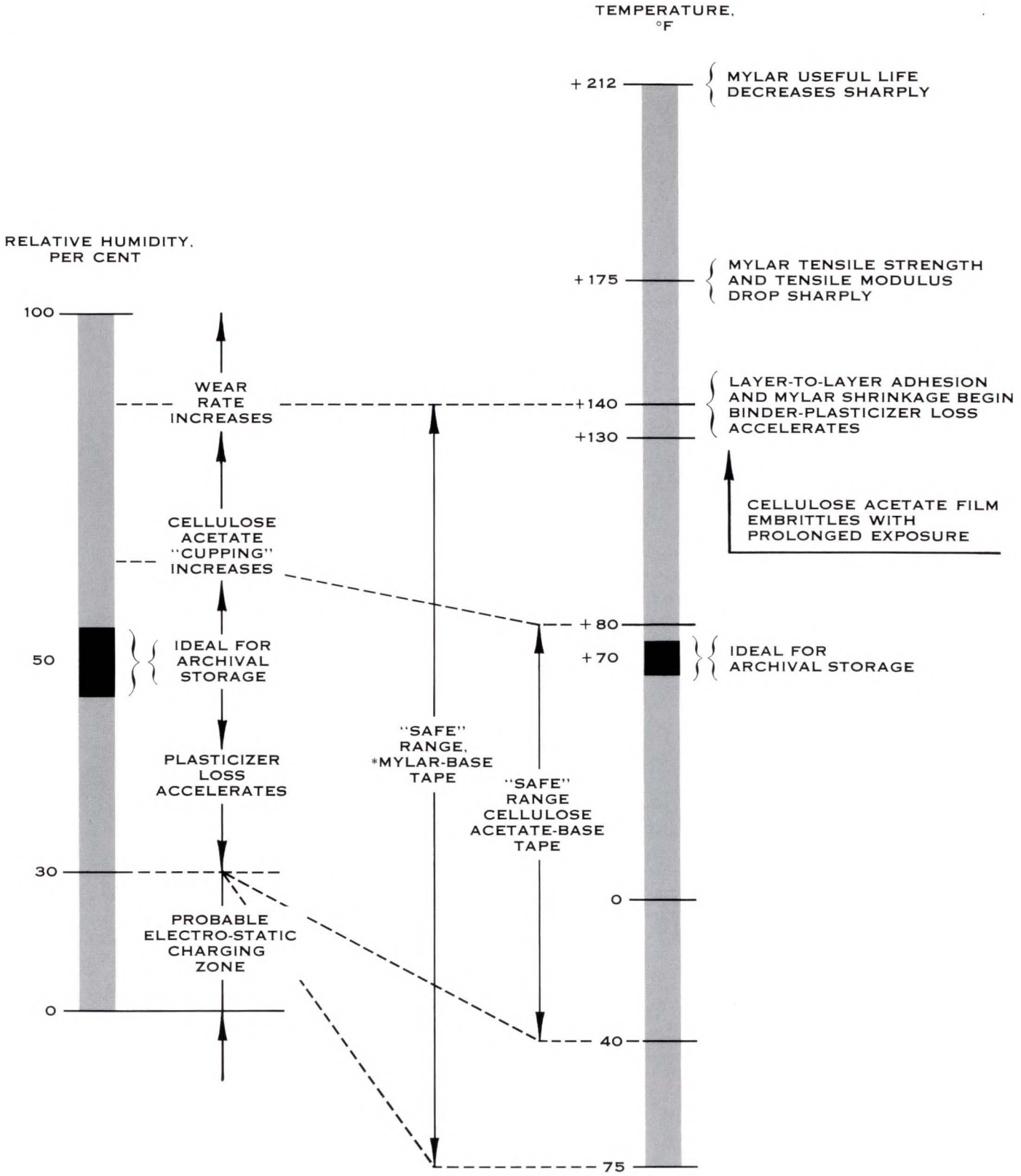

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